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Finite Element Simulation of Electro Magnetic Welding with Varying Air Gap

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ABSTRACT

Magnetic pulse welding process, one of high speed welding processes, uses electromagnetic force from discharged current through a working coil which develops a repulsive force between the induced currents flowing parallel and in the opposite direction in the work piece to be welded. Coils of specific geometry and material combinations are essentially required to achieve precise and successful electromagnetic (EM) welding. The aim of the present research is to assess the weldability criteria of high speed magnetic pulse welding for tubular jobs of Al, Cu and SS combinations using finite element analysis. A circular design of EMW coil is proposed to perform EMW simulations while varying the air gap between the outer tube and inner tube of different work pieces and voltages. A 3-dimensional electromagnetic FE-model has been developed to analyze the distribution of electromagnetic force and magnetic flux density. Results of electromagnetic forces and magnetic flux density acquired during EMW simulations of various material combinations are shown here. The data shown in the results provides a guideline to choose EM welding parameters for further experimentations. The demonstrated results will assist future researchers to develop a better methodology for coil design and to further explore the field

Keywords : EMW, CATIA,FEA,ANSYS, FE-model, Electromagnetic

I. INTRODUCTION

Welding, as existing fusion welding, generally causes not only defects, such as solidification, cracking, porosity and oxidation, but also transformation and corrosion. For this reason, more attention has been paid to magnetic pulse welding process as a kind of solid-state welding, these days. Electromagnetic (EM) welding is an impact welding process of joining two similar or dissimilar metals by removing oxide layer and by creating a high velocity impact by Lorentz forces generated due to the electromagnetic field and damped sinusoidal transient current. It offers many distinct advantages, provided it is used, taking into account its limitations. continuously as a function of position along certain dimension (typically the radius and thickness) of the structure to achieve a require function. FGMs can provide designers with tailored material response and exceptional performance in thermal environments. For example, the Space

Shuttle utilizes ceramic tiles as thermal protection from heat generated during re-entry into the Earth's atmosphere. An FGM composed

magnetic pulse welding. For this, they developed a FEM model which was used to analyze the distribution of electromagnetic force; after that, distribution of electromagnetic force, results of numerical analysis and experimental results for verifying the developed FE- model were compared. Published literature on numerical modeling of EM welding of flat sheets and axisymmetric jobs are scarce. Further detailed study of the effect of process parameters, coil design, etc. on strength of electromagnetic welding of tubular jobs of dissimilar materials has not been reported yet. Kim et al. [13] have investigated the efficiency of the joint designs for EMW of ring- shaft assembly. Aizawa T [7] et al. have demonstrated the Magnetic pulse welding method and its application for several aluminum alloys (A1050, A2017, A3004, A5182, A5052, A6016, and A7075). They've also reported the welding process parameters.

II. METHODS AND MATERIAL

2.1 Design of Working Coil

There are no given set of rules or guidelines to design the welding coil. Thus, a new approach has been discussed in this project. A single turn welding coil has been considered in this project. Firstly, the geometry of the welding coil is decided, which not only depends on the geometry of the work-piece to be welded, but also on the welding direction, according to the application. Secondly, distribution of electromagnetic force by the interaction between working coil and outer pipe is investigated after selecting materials whose electric resistance is low and those who have enough strength possible to resist electromagnetic force on processing.

The values of process parameters like capacitance were assumed from literature survey and from standard information available. To meet the demands of higher energy and higher ringing frequency, it is advised to use capacitance bank of higher voltage and low capacitance for low conductivity materials. R = 10 mΩ, L = 70 nH and C = 400 μF are the process parameters for the given study.

For welding of tubular jobs there are two types of working coils viz. expansion type and compression type. A compression type welding coil is the solenoid type, which houses the work pieces within itself, and the welding takes place from outside direction to inside direction. Expansion coil is placed inside the materials to be welded and welding takes place from inside to outside direction. The compression type coil was chosen in this project to weld tubular jobs because it is located outside of the work pieces. In addition, it has no size limit, as well as it only requires a simple connection to the power source.

2.1 3D-Model generation of EMW Coil

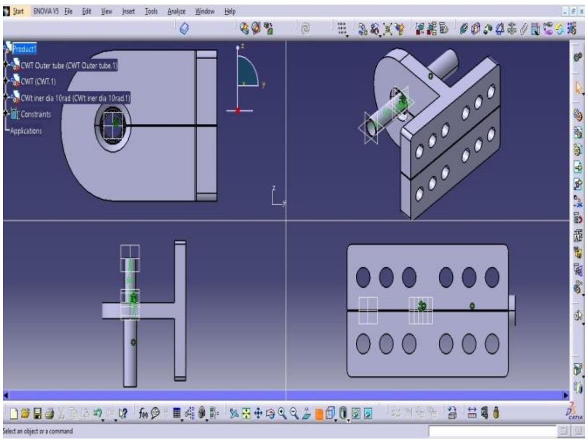

Fig 2.1 3D CAD model of working coil with tubular work pieces

The electromagnetic working coil is the most critical component of the electromagnetic welding process. The material of working coil should be conductive i.e. it should allow the current and magnetic lines of flux to pass through it. Also, it should be mechanically strong to sustain deformation and electromagnetic forces during the welding process. Therefore, Stainless steel and Copper have emerged as the suitable candidates for the working coil material in this project. Also, it can be seen from the figure that the coil is tapered near the inner end towards the work piece. Corresponding to this area is the region where welding takes place. The reason for making it tapered is that, more current will pass through the lesser area, which in turn will result in more magnetic lines of flux passing through it, which in turn will generate more electromagnetic force, thus resulting in a better weld.

III. RESULTS AND DISCUSSION

The 3D CAD model of circular coil generated in the previous chapter is then imported in ANSYS Maxwell 3D. ANSYS Maxwell is the electromagnetic field simulation software tasked with designing and analyzing 3-D and 2-D electromagnetic and electromechanical devices, including motors, actuators, transformers, sensors and coils. Maxwell uses the accurate finite element method to solve static, frequency-domain, and time-varying electromagnetic and electric fields. After importing the 3D CAD model into ANSYS Maxwell 3D, we have created a region (environment) where the boundary conditions like insulation sheet, coil terminals, windings, etc. are applied.

After giving the boundary conditions, time varying current, as stated in equation 3, is provided as input to the 3D FE model. Coil materials of SS and Cu have been used for the welding simulation of various material combinations viz. Al-SS, Cu-SS, and SS-SS with varying air- gap from 0.5mm, 1mm and 2mm for each of the combinations. At 12KV the maximum current was generated at 7μs and it was found out to be 0.591MA. At 14KV, the maximum current was generated at 7μs and it was found out to be 0.689MA. And at 18KV, maximum current was again generated at 7μs and it was approx. 0.887MA. Detailed FEM simulation results have been shown below.

3.1 Simulation of EMW of Al-SS work pieces with Cu coil

The following simulation results (Fig. 4.1 to 4.3) are shown for electromagnetic welding of Al-SS tubular work pieces with Cu coil at an air gap of 0.5, 1.0 and 2.0 mm respectively. At an air gap of 0.5mm, for the process parameters of 12KV, 70 nH and 400 μF, the maximum magnetic field density generated for coil and work pieces is found out to be 19.58T and 26.25T resp. and the maximum electromagnetic force generated is 195.83N. Fig (3.1) shows the results.

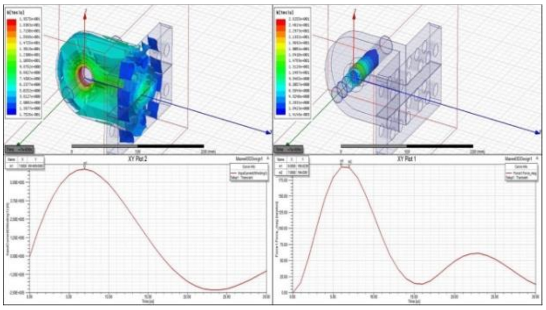

Fig 3.1

From the comparison of various responses of the FG shaft without and with temperatures consideration, it has been noticed that the FG shaft is more stable in case of without temperature consideration than that of with temperature consideration.

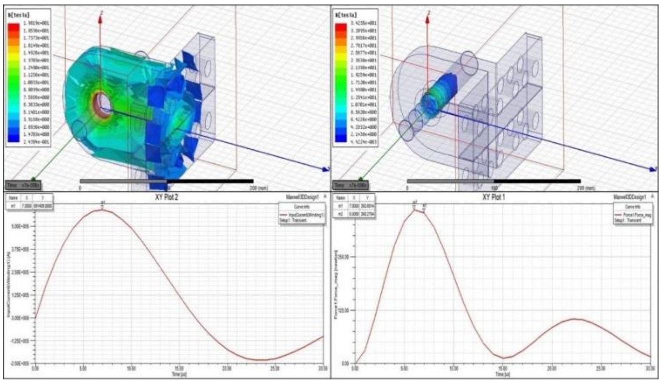

Fig 3.2. Cu Coil, AL – SS work pieces, 0.5mm Air-gap

At an air gap of 1mm, for the process parameters of 12KV, 70 nH and 400 μF, the maximum magnetic field density generated for coil and work pieces is found out to be 19.82T and 34.23T resp. and the maximum electromagnetic force generated is 360.276N. Fig (3.2) shows the results.

At an air gap of 2mm, for the process parameters of 12KV, 70 nH and 400 μF, the maximum magnetic field density generated for coil and work pieces is found out to be 19.48T and 27.31T resp. and the maximum electromagnetic force generated is 221.97N. Fig (3.3) shows the results.

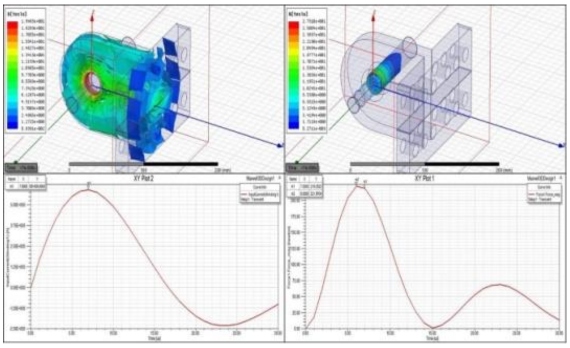

Fig 3.3 Cu Coil, AL – SS work pieces, 2mm Air-gap

IV. RESULTS AND DISCUSSIONS

Welding simulations have been established between the similar metal combinations of Stainless Steel – Stainless Steel, and between dissimilar metal combinations of Aluminium – Stainless Steel, and Copper – Stainless Steel. Table 1. shows a detailed result of all the welding simulations carried out at different welding parameters.

The voltage was varied (from 12KV to 18KV) for different material combinations, because it's learnt from the literature, and verified from our results that, Copper being more dense than Stainless Steel, requires more energy to be welded. More density leads to less magnetic lines of flux passing through the material, which results in lesser Electromagnetic or Lorentz force. Also, energy required for Stainless steel is more as compared to Aluminium. Thus the energy requirement goes on decreasing successively for Stainless Steel, Copper and Aluminium.

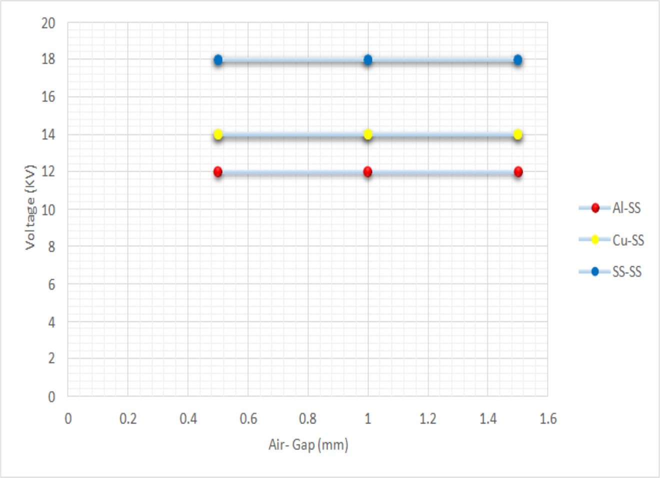

Fig. 4.1 Air-gap (mm) v/s Voltage(KV)

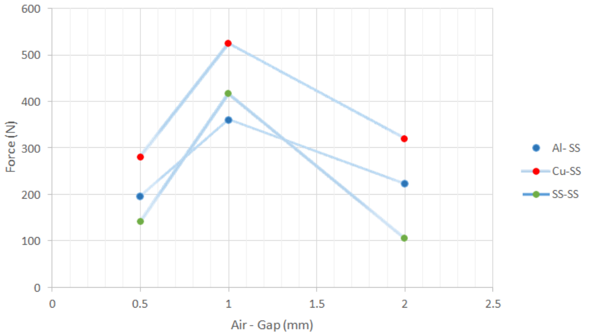

Fig. 4.2 Air-gap (mm) v/s Force(N)

V. CONCLUSION

A comprehensive approach considering foregoing weldability criteria for magnetic pulse welding should be adopted. The process parameters in MPW are interrelated. A moderate input voltage at an optimum air gap could achieve a sound joint. The correctness of the computational model needs to be validated in actuality. This analysis gives important inputs for the predictive design and the standardization procedures. The publication of analytical results will provide highest possible information and can be utilized for further analysis and evaluation by future researchers.

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